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Apparatus for multi-stage heat exchange, and process for producing an apparatus of this type

The present invention relates to an apparatus for multi-stage heat exchange, and to a process for producing an apparatus of this type.

The demands imposed on modern cooling and air-conditioning systems in vehicles are constantly rising. This is partly attributable to the fact that the overall demand for cooling is increasing and partly to the need to improve the efficiency of cooling systems, the boundaries of which are being pushed further and further. The improved utilization of heat sources and heat sinks can lead to a higher degree of utilization of an overall concept and also to a reduction in consumption. The configuration of heat exchangers plays a central role in this overall concept.

Cooling and heating concepts of the current state of the art generally provide for single-stage heat transfer in heat exchangers. In the process, fluids, such as for example coolant, refrigerant, oil, exhaust gas or charge air, are cooled or heated. The efficiency which can be achieved with single-stage temperature control is normally limited. Therefore, to improve the performance of cooling circuits, it is in some cases appropriate for a fluid to be cooled or heated over two stages. This is possible if, in addition to the fluid whose temperature is to be controlled, there are two further fluids which are at two different temperature levels.

In general, one drawback of the two-stage control of the temperature of the fluids is that the use of two heat exchangers connected in series in the conventional way entails considerably increased costs as well as a greater installation space requirement.

The invention is therefore based on the object of providing an apparatus in which the at least two-stage cooling or heating of a fluid can be of compact and inexpensive configuration.

According to the invention, the object is achieved by an apparatus as claimed in claim 1. The process according to the invention for producing an apparatus of this type forms the subject matter of claim 20. Preferred embodiments and refinements form the subject matter of the subclaims.

The apparatus according to the invention for heat exchange has at least three flow devices, through which at least one flowable medium (fluid) flows. After they have flowed through the individual flow devices, it is also possible for at least two of the at least three fluids to be mixed in the heat exchanger and discharged together.

It is preferable for the majority of the heat, preferably over 60%, in particular up to 70%, to be transferred in the first flow assembly of the cooling or heating. In the context of the present invention, the term flowable media or fluids is to be understood as meaning liquid and/or gaseous media of any desired viscosity, such as in particular, although not exclusively, oils, liquids, in particular with a high heat of evaporation, water, air or gases as well as refrigerants which can evaporate or condense. The flowable media may in this case also contain additives, for example for inhibiting corrosion.

Furthermore, the apparatus according to the invention has at least one fluid inflow device, at least one fluid collection and/or distribution device and at

least one fluid outflow device for at least one flow device through which substantially liquid fluids flow.

According to the invention, at least two flow assemblies are provided, each having at least two flow elements, which are arranged in such a manner that different fluids flow through them alternately. Furthermore, the flow elements belonging to a flow device through which substantially liquid fluids flow are connected in a substantially gastight and liquid-tight, positively locking and/or nonpositively locking and/or cohesive manner to at least one fluid collection and/or distribution device.

According to the invention, the main directions of flow of all the fluids in the flow elements lie in planes that are substantially parallel to one another. Furthermore, two flow assemblies of the apparatus according to the invention are directly connected in series in a positively locking and/or nonpositively locking and/or cohesive manner and/or flow-connected by means of a fluid distribution device, at least with respect to one flow device.

In this context, a flow device is to be understood as meaning a device through which a liquid or gaseous medium can flow and which, in the case of the flow devices through which substantially liquid fluids flow, is delimited in a substantially gastight and liquid-tight manner with respect to the space surrounding it. The flow devices are in this case formed by flow elements which are flow-connected in series and/or in parallel.

In a preferred refinement of the apparatus according to the invention, these flow elements, at least in sections, are formed by in particular, although not exclusively, hollow disks, flat tubes, plates and/or

layers. In this context, hollow disks, plates or layers are to be understood as meaning substantially gastight and liquid-tight hollow bodies with inlet and outlet openings, the length and width dimensions of which are considerably greater than their height. In this context, the term flat tubes is to be understood as meaning tubes which when seen in cross section have a long side and a side which is significantly shorter than this long side.

The flow elements may have one or more flow passages for the medium flowing through them. They may run in a straight line but they may also have a plurality of curved sections. In addition, the flow elements may also have twisted sections, i.e. sections in which the flow element is turned and/or wound in on itself.

In the context of the present invention, a fluid distribution and/or collection device, in the case of the flow devices through which substantially liquid fluids flow, is to be understood as meaning substantially gastight and liquid-tight hollow bodies within which fluids can flow and within which these fluids are collected. At the same time, however, these fluid distribution and/or collection devices can also be used to distribute the respective fluids between a plurality of flow elements and/or to collect them again from various flow elements.

In the context of the present invention, the term flow-connected is to be understood as meaning that a fluid can flow between the flow elements, fluid distribution and/or collection devices. The term substantially gastight and liquid-tight is to be understood as meaning in particular, although not exclusively, a division by separating devices, so that it is impossible for any fluid to flow past the respective separating device along certain directions of the flow

devices, flow elements, fluid distribution and/or collection devices.

The term direction of flow or main direction of flow of a fluid is to be understood as meaning the direction which the fluid preferably adopts within a flow device, a flow element and/or a fluid distribution and/or collection device, disregarding locally limited changes in direction of the fluid.

In a preferred embodiment, the fluid distribution and/or collection devices are, in the broader sense, collection and/or distribution tubes.

In another preferred embodiment, at least one fluid collection and/or distribution device is formed at least in part from longitudinal-side openings in the flow elements, a first number of simple openings forming fluid inlets and fluid outlets with respect to adjacent flow elements, and sealing devices being arranged around a second number of openings, in order to form passages in the corresponding flow element, through which passages flow elements adjacent to this flow element are flow-connected.

In the context of the invention, the first number of longitudinal-side openings in flow elements, preferably in hollow disks, plates or layers, are to be understood as meaning in particular, although not exclusively, round punched-out apertures or drilled holes which are provided in the significantly longer and wider sides of the flow elements.

The sealing devices around the second number of longitudinal-side openings in flow elements, preferably in hollow disks, plates or layers, in the context of the invention are to be understood as meaning in particular, although not exclusively, stamped

projections, which adjoin the adjacent flow element in a cohesive and/or positively locking and/or nonpositively locking manner, in the corresponding flow element or sealing rings.

It is preferable for partition walls to be provided in a substantially gastight and liquid-tight manner in individual openings, allowing preferred control of the fluid distribution by in particular, although not exclusively, stacking identical plate-like flow elements on top of one another.

In another preferred embodiment of the apparatus according to the invention, turbulence-generating and/or turbulence-increasing shaped elements are preferably provided within the flow device, which shaped elements in particular contribute to increasing the heat transfer coefficient between the fluids of the various flow devices. It is preferable for these turbulence-generating or turbulence-increasing shaped elements to be taken from a group which includes in particular, although not exclusively, fins, webs, studs, grooves, stamped indentations or milled-out sections.

In another preferred embodiment, the turbulence-generating and/or turbulence-increasing shaped elements are arranged in at least one flow element and/or between at least two flow elements. Furthermore, the profile of at least one flow element preferably has turbulence-generating and/or turbulence-increasing properties.

In another preferred embodiment, turbulence inlays are provided, preferably to be laid in at least one flow element, in particular, although not exclusively, in hollow disks, plates and/or layers.

In the context of the invention, turbulence inlays are to be understood as meaning in particular, although not exclusively, metal sheets which have turbulence-generating and/or turbulence-increasing shaped elements, such as for example fins, webs, studs, grooves, stamped indentations and/or milled-out sections and are laid in the flow elements, in a manner which simplifies production, preferably with external dimensions corresponding to the internal dimensions of the flow elements, and preferably with punched-out apertures corresponding to the distribution devices with leaktightness device, in particular the stamped projections in the flow elements, for the passages through which adjacent flow elements are flow-connected.

In another preferred embodiment of the apparatus according to the invention, at least two flow elements through which different fluids flow are connected on the longitudinal sides in a positively locking and/or nonpositively locking and/or cohesive manner.

In another preferred embodiment, at least two flow elements through which the same fluid flows are connected on the longitudinal sides by means of in particular, although not exclusively, the turbulence-generating and turbulence-increasing shaped elements which have their own profile and/or are arranged between them, in such a manner that at least one cavity which is thereby formed between these flow elements forms a flow element for a different fluid.

In another embodiment, the joins between the flow elements are taken from a group which includes soldered joins, welded joins or adhesively bonded joins.

In another preferred embodiment, at least one sealing element, which is formed in particular, although not

exclusively, by separating elements and/or hollow elements which are empty of fluid, is provided at least between two flow elements through which different fluids flow.

It is preferable for at least one sealing element to be arranged between flow assemblies which are in series.

In another preferred embodiment, at least one of the sealing elements has in particular, although not exclusively, a hollow element which is empty of fluid, a leaktightness control opening. This proves advantageous in particular during production of the apparatus according to the invention, since then the individual flow devices are first of all individually filled with their respective fluids, and should the respective flow device prove not to be leaktight, for example as a result of a fault in the production process, it is possible for the fluid which escapes to be collected in the hollow or blind element, which is initially empty of fluid, and to demonstrate the lack of leaktightness by emerging at the leaktightness control opening.

The method of first of all filling each individual flow device with its corresponding fluid also makes it possible for the gastightness and liquid-tightness according to the invention of the various flow devices with respect to one another to be checked as a result of the fluid which has in each case been introduced passing into a second flow device.

In another preferred embodiment of the apparatus according to the invention, at least one of the sealing elements has at least one leaktightness sensor, which causes a physically perceptible signal to be output in the event of a fluid escaping from one of the flow devices.

In another preferred embodiment, at least two flow assemblies are separated from one another in a substantially thermally insulating manner, for example simply by being arranged spatially spaced apart, and/or alternatively by means of hollow elements that are empty of fluid in particular arranged between them.

In another preferred embodiment, shaped elements are provided within at least one flow element, which shaped elements, at least in sections, alter the main direction of flow of the fluid flowing within the flow element.

In another embodiment, at least one flow device has admixed with it, via at least one further inflow device, a fluid, in particular, although not exclusively, a fluid which corresponds to the fluid in this flow device.

In another preferred embodiment, the series connection according to the invention of at least two flow assemblies with respect to at least one flow device is effected in such a manner that the temperature gradient of the fluid of this flow device along the flow path of this fluid from the fluid inflow device to the fluid outflow device of this flow device has a substantially constantly decreasing magnitude with respect to each of the other fluids flowing through the flow assemblies of the flow assembly series connection.

In another preferred embodiment, fluids are mixed in the heat exchanger, it being possible for different proportions of the overall fluid to flow through different flow elements.

Another preferred embodiment allows a fluid to be divided in the heat exchanger, it being possible for

different proportions of the divided fluid to flow through different flow elements.

In another preferred embodiment, the heat exchange in individual flow assemblies takes place by condensation or evaporation of a fluid.

In further preferred embodiments, the individual flow assemblies can be operated as crosscurrent, countercurrent or cocurrent heat exchange units.

In another preferred embodiment, the heat exchanger is part of a cooling circuit, and the individual flow assemblies are supplied with the fluid via a further low-temperature and/or high-temperature cooling circuit.

In another preferred embodiment, the heat exchanger is used as an at least two-stage heat exchanger for use in land-based vehicles, aircraft or water-borne vehicles, in particular for exhaust-gas cooling for an internal combustion engine.

Further advantages, features and possible applications of the present invention will emerge from the following description of exemplary embodiments, in conjunction with the figures, in which:

Figure 1 shows a diagrammatic section through a heat exchange apparatus according to the invention with disk stacks arranged on top of one another as flow assemblies;

Figure 2 shows a perspective partially exploded view of the two-stage heat exchanger from Figure 1;

Figure 3 shows an upper longitudinal section view of two types of disk for another embodiment of the heat exchange apparatus according to the invention;

Figure 4 shows an upper longitudinal section view of two types of disk for another exemplary embodiment of the heat exchange apparatus according to the invention;

Figure 5 shows an upper longitudinal section view of two types of disk for another exemplary embodiment of the heat exchange apparatus according to the invention;

Figure 6 shows a perspective ghosted view of another exemplary embodiment of the heat exchange apparatus according to the invention with flow assemblies arranged on top of one another;

Figure 7 shows a perspective ghosted view of another exemplary embodiment of the heat exchange apparatus according to the invention with flow assemblies arranged next to one another;

Figure 8 shows a perspective ghosted view of another exemplary embodiment of the heat exchange apparatus according to the invention with flow assemblies for a gaseous fluid 2 arranged on top of one another;

Figure 9 shows a perspective ghosted view of another exemplary embodiment of the heat exchange apparatus according to the invention with flow assemblies arranged on top of one another and an alternative arrangement of an outflow device.

Figure 10 shows a perspective ghosted view of another exemplary embodiment of the heat exchange apparatus according to the invention with flow assemblies arranged next to one another and a common fluid outflow device;

Figure 11 shows two plan views of further exemplary embodiments of the heat exchange apparatus according to the invention;

Figure 12 shows a cooling circuit in which the heat exchanger shown in Figure 10 has been integrated.

A first exemplary embodiment of the invention will now be described with reference to Figures 1 and 2. These figures show a diagrammatic section through a two-stage heat exchanger, the flow elements of which are disks and the heat exchange or flow assemblies of which are formed by disk stacks arranged on top of one another with a hollow disk arranged between them, and a perspective partially exploded view of the same heat exchanger, respectively.

In Figure 1, the fluid 1 flows in at the top left via the inflow device 10 through the cover 5 into the flow assembly 120 and passes first of all through a second opening 100 with stamped projection through the top disk 22 into the top disk 12 as flow element for fluid 1. From there, the fluid 1 has two possible directions of flow, namely on the one hand substantially diagonally over the top disk 12 to the first opening 102 illustrated in Figure 2, in which case along this path heat is exchanged with the fluid 2 flowing through the disks 22 located above and/or below.

Then, fluid 1 passes through the first opening 102 through a corresponding stamped projection in the disk 22 below, which in turn has fluid 2 flowing through it, into the following disks 12. On the other hand, the first opening 101 illustrated in Figure 2 also allows passage through the disk 22 below to the following disks 12. However, a direct flow path for fluid 1 directly through the first and second openings of the

disks of both flow assemblies from the inflow device 10 to the outflow device 11 without the fluid 1 having to flow across the disks 12 of the lower flow assembly 130 is blocked by means of the partition wall 71.

Finally, from the bottom disk 12 of the upper flow assembly 120, fluid 1 flows through a corresponding stamped projection in the blind disk 7 into the flow assembly 130 which is thereby connected in series with flow assembly 120 with regard to fluid 1 and which forms a second heat exchange stage, the disks 12 of which produce similar flow paths between the disks 32 through which fluid 3 flows, which now allows heat exchange between fluids 1 and 3.

The partition walls 72 and 73, as well as 74 and 75, separate the disks 22, as the main part of the flow device for fluid 2, from the disks 32, as the main part of the flow device for fluid 3. Finally, fluid 1 emerges from the two-stage heat exchanger 9 through the base 6 and the outflow device 11.

In a similar way, fluid 2 flows through the disks 22 of the upper flow assembly 120 and fluid 3 flows through the disks 32 of the lower flow assembly 130, with the outflow devices 21 and 31 for fluids 2 and 3, respectively, corresponding to the inflow devices 20 and 30, in each case being arranged on the same side, i.e. at the top for fluid 2 and at the bottom for fluid 3.

The blind disk 7, which is empty of fluid, on the one hand allows thermal insulation of the flow assemblies 120 and 130, which are preferably at different temperature levels, and on the other hand is also used to check the leaktightness and to prevent fluids 3 and 2, in operation, from becoming mixed unnoticed in the event of leaks occurring in the two flow devices and/or

fluid circuits. The blind disk 7 is closed on all sides and has a small opening 8 to the outside on the side of its edge web. In the event of a leak, the respective fluid can flow out through this opening and does not penetrate into a different flow device.

Turbulence-generating fins or elements may be laid between the disks 12, 22 and 32, and/or the disks themselves have stamped-in fins, webs, and/or studs (not shown here). A predetermined compressive strength is achieved by soldering the elevations in the form of the inlays or stamped indentations from disk to disk.

Figure 3 illustrates an upper longitudinal section view of the two types of disk for a two-stage heat exchanger which is formed from disks and in which two fluids within the first type of disk 15 are separated by means of two parallel webs 77, with in each case two smaller first openings 121, 122 and 131, 132 being provided as inlet and outlet for fluids 2 and 3. Furthermore, the first type of disk 15 has two larger second openings 113 and 114 with an encircling stamped projection as a passage opening for fluid 1.

By contrast, the second type of disk 25 in each case has two smaller second openings 123 and 124, and 133 and 134, with an encircling stamped projection for the passage of fluid 2 or 3, respectively, through the second type of disk 25, as well as two larger first openings 111 and 112 as inlet and outlet for fluid 1 into and out of the second type of disk 25.

Figure 4 illustrates another variant of the two types of disk for a two-stage heat exchanger formed from disks, in which fluids 2 and 3 are supplied via separate fluid inflow devices. The inlet and passage of fluid 2 and 3 into or through the first type of disk 17 is effected by means of two smaller third openings 126

and 136 with an interrupted encircling stamped projection. Two smaller second openings 125 and 135 with an encircling stamped projection allow fluids 2 and 3 to pass through. Fluids 2 and 3 are mixed within the first type of disk 17 and discharged via an additional, larger first opening 1231.

An additional, larger second opening 1232 with encircling stamped projection located in the second type of disk 27 allows the mixture of fluids 2 and 3 to pass through the second type of disk 27. It is preferable for fluids 2 and 3 to be one fluid which, however, is at different temperature levels at the fluid inflow devices. In this embodiment, the mixing of the fluids means that there is no need for the flow devices to be separated by means of the webs 77 shown in Figure 3. A characteristic of this embodiment is that the fluid 2 exchanges heat in cocurrent with fluid 1, and fluid 3 exchanges heat in countercurrent with fluid 1.

Figure 5 represents an upper longitudinal section view of the two types of disk for a two-stage heat exchanger formed from disks as shown in Figure 3, with an additional, larger first opening 141 acting as inlet for a fluid 4, preferably corresponding to fluid 1, into the second type of disk 26 being provided in the second type of disk 26. It is preferable for fluid 4 to be at a different temperature level than fluid 1 and/or it may also contain, for example, corrosion-inhibiting additives.

Figure 6 shows a perspective ghosted view of a two-stage heat exchanger, the flow elements of which are formed from flat tubes 40 and cavities 50 between them, the flow assemblies according to the invention for fluids 1 and 2 or fluids 1 and 3 being arranged on top of one another, and the fluid 1 whose temperature is to

be controlled having its inlet and outlet on the same side. Cooling fins 99 which increase the surface area and contribute to increasing the heat transfer coefficient between fluids 1 and 2 are indicated between the flat tubes. The compressive strength is increased by soldering the cooling fins 99 from flat tube to flat tube.

Figure 7 shows a perspective ghosted view of a two-stage heat exchanger, the flow elements of which are formed from flat tubes 41 and from cavities 51 between them, with the flow assemblies according to the invention for fluids 1 and 2 or fluids 1 and 3 being arranged next to one another and the fluid 1 whose temperature is to be controlled having its inlet and outlet on opposite sides.

Figure 8 shows a perspective ghosted view of a two-stage heat exchanger, the flow elements of which are formed from flat tubes and from cavities between them, with the flow assemblies according to the invention for fluids 1 and 2 or fluids 1 and 3 being arranged on top of one another, in accordance with Figure 5, but with the possibility of dispensing with a feed and a discharge and a housing for the flow assembly for fluids 1 and 2, on account of the use of a gaseous fluid 2, preferably the ambient air. The direction of flow of the fluid 2 is indicated by the arrow illustrated next to the corresponding reference numeral.

Figure 9 illustrates a perspective ghosted view of a two-stage heat exchanger in accordance with Figure 5, with the second heat exchange stage in the form of the flow assembly for fluids 1 and 3 being used or dispensed with depending on the alternative arrangement, indicated by the dashed outflow direction of fluid 1, of the outflow device for fluid 1 on the

same side as or the opposite side to the inflow for fluid 1.

Figure 10 illustrates a perspective ghosted view of a two-stage heat exchanger as shown in Figure 7, in which it is possible to use more flat tubes than in Figure 7. A characteristic feature of this exemplary embodiment is that fluids 2 and 3 are one fluid, similarly to in Figure 4. In this exemplary embodiment, fluids 2 and 3 flow into the heat exchanger at different mass flow rates and temperatures. The two fluids mix with one another substantially in the common fluid collection device for fluids 2 and 3 and then flow out in mixed form via the common fluid outflow device. Figure 10 additionally shows a plan view of this exemplary embodiment which illustrates that the flow assembly comprising the fluids 1 and 3 is operated predominantly in cocurrent, the flow assembly comprising the fluids 1 and 2 is operated predominantly in countercurrent and not predominantly in crosscurrent in accordance with Figure 7.

This variant has advantages with regard to the cooling of exhaust gases. In the high-temperature flow assembly (HT flow assembly) comprising the fluids 1 and 3, in accordance with the plan view, a very large amount of coolant flows in cocurrent with the very hot exhaust gas through the cooler. The cocurrent arrangement substantially prevents the coolant from boiling. In the low-temperature flow assembly (LT flow assembly) comprising the fluids 1 and 2, a considerably smaller cool mass flow of coolant flows in countercurrent to the exhaust gas, which has already been greatly cooled. Here, countercurrent connection can be permitted, since there is no longer a risk of boiling, on account of the exhaust-gas cooling which has already taken place. The countercurrent connection has the advantage that the

heat exchange between exhaust gas and coolant is very high and the exhaust gas can be intensively cooled.

Figure 11 shows that the position of the fluid inflow and outflow device, depending on the particular application, may also be set in such a way that the flow through the entire cooler is in countercurrent (A) or cocurrent (B). This is possible if there is no risk of the coolant(s) boiling.

Figure 12 diagrammatically depicts the incorporation of a cooler 300 as shown in Figure 10 for the case of exhaust gas cooling for an internal combustion engine 400. Numerous circuit arrangements are conceivable; it is advantageous if the LT flow assembly 311 of the cooler 300 has a low mass flow, which is cooled to a very low temperature by air in a separate low-temperature cooler 310, flowing through it. This low mass flow is branched off from the main flow downstream of the main air cooler 320 and cooled in the low-temperature cooler 310. The HT flow assembly 321 of the two-stage cooler 300 has a greater mass flow at a higher temperature level, which is branched off directly from the mass flow of coolant flowing to the main air cooler 320, flowing through it.

It is also conceivable for the two-stage heat exchanger to have a dedicated coolant circuit, i.e. not to be incorporated in the actual engine cooling circuit. It is also possible for the LT circuit to have a dedicated pump.